

THE RELATION BETWEEN THE ATOMIC VOLUMES OF ELEMENTS PRESENT IN IRON AND THEIR INFLUENCE ON ITS MOLECULAR STRUCTURE.

IN a lecture on the Hardening and Tempering of Steel, published in November last (NATURE, vol. xli. pp. 11, 32), an attempt was made to set forth the prominent facts developed in recent researches, more especially those of M. Osmond, which tend to prove that iron, like many other elements, can pass from the normal state to an allotropic one. It was shown that as a mass of iron or steel cools down, there are at least two distinct evolutions of heat, one occurring at a variable temperature not higher than 855°C ., the other at a more constant temperature, near 650°C . From a long series of most patient investigations, Osmond argues that there are two kinds of iron, one [hard] β iron, and the other [soft] α iron. The molecular change from β to α iron is indicated by the first evolution of heat in the cooling mass of iron or steel, and at this point the cooling mass of iron regains the magnetic properties which it loses at higher temperatures. The second evolution of heat only occurs in carburized iron or steel, and marks the point at which carbon itself changes from the dissolved or 'hardening-carbon,' to the state of combined or 'carbide-carbon.' In highly carburized steel, the two points at which heat is evolved coincide, and experimental evidence has been given (*loc. cit.* p. 34) as to the abnormal molecular weakness which is exhibited when a very hot bar of such steel cools down to about 660°C . In a recent communication to NATURE (February 20, p. 369), Prof. Carl Barus, of Washington, has pointed out, with reference to this molecular weakness, "that when iron passes through the temperature of recalescence its molecular condition is almost chaotic"; whilst with regard to Osmond's view that α iron passes to β iron when submitted to any stress which produces permanent deformation of the mass, Prof. Barus says that "there is reason to be urged even in favour of the extreme view" that such molecular change may be produced in most metals. In the lecture at Newcastle, I expressed the belief (NATURE, *loc. cit.*) that it would be shown that the influence of small quantities of other elements on masses of iron would be found not to be at variance with the periodic law. I had already given experimental evidence to show that the action of small quantities of impurity on the tenacity of gold was closely in accordance with that law, but in the case of iron it was difficult to say what property of the metal would be most affected by the added matter. It appeared safe, however, to point to the possibility that the direct connection with the periodic law would "be traced by the effect of a given element in retarding or promoting the passage of ordinary iron to the allotropic state," a point of much importance, as the mechanical properties of the metal must depend on the atomic arrangement in the molecules.

I am glad that so eminent an authority and admirable experimenter as M. Osmond has satisfied himself as to the probable accuracy of this view. In two recent papers communicated to the Académie des Sciences, the results of his experiments are given, and the following is a translation of the later of these (*Comptes rendus*, vol. cx. p. 346):—

"Within the last few years and quite recently (*Comptes rendus*, Séances des 26 octobre et 6 décembre 1886, 4 avril 1887, et 3 février 1890), I have had the honour to submit to the Academy facts relating to the allotropic modifications of iron, and to the part played in such changes by foreign bodies alloyed with the mass. Prof. Roberts-Austen, by studying the effect produced on the mechanical properties of gold by the addition of the same weight (about 0.2 per cent.) of seventeen foreign metals, has discovered a curious relation between the results ob-

tained and the position occupied by the added metals in the periodic classification (Phil. Trans. Roy. Soc., vol. clxxix. p. 339, 1888). Prof Roberts-Austen has deduced from this that an analogous relation should exist for iron, but the irons and steels of commerce are such complex products, and the same metal may assume such different aspects, that the relation in question is not readily apparent from a study of their mechanical properties.

"In reviewing my former experiments with these new ideas as guides, it appeared to me that the law of Roberts-Austen was well based, and new experiments undertaken to verify it have only confirmed my first view.

"The foreign elements whose action on the critical points of iron I have studied experimentally with more or less completeness, are ranged as follows in two columns in the order of their atomic volumes:—

I.	Atomic volume.	II.	Atomic volume.
Carbon	3.6	Chromium	7.7
Boron	4.1	Tungsten	9.6
Nickel	6.7	Silicon	11.2
Manganese	6.9	Arsenic	13.2
Copper	7.1	Phosphorus	13.5
		Sulphur	15.7

"The elements in column I., whose atomic volumes are smaller than that of iron (7.2), delay during cooling, *ceteris paribus*, the change of β [hard] iron to α [soft] iron, as well as that of 'hardening-carbon' (*carbone de trempe*) into 'carbide-carbon' (*carbone de recuit*). For these two reasons they tend to increase, with equal rates of cooling, the proportion of β iron that is present in the cooled iron or steel, and consequently the hardness of the metal. Indeed, their presence is equivalent to a more or less energetic hardening.¹

"On the other hand, the elements of column II., whose atomic volumes are greater than that of iron, tend to raise or at least to maintain near its normal position, during cooling, the temperature at which the change of β to α iron takes place; further, they render the inverse change during heating more or less incomplete, and usually hasten the change of 'hardening-carbon' to 'carbide-carbon.'²

"Thus they maintain the iron in the α [soft] state at high temperatures, and must therefore have the same effect in the cooled metal. In this way they would act on iron as annealing does, rendering it soft and malleable, did not their individual properties, or those of their compounds, often intervene and partially mask this natural consequence of their presence.

"The essential part, therefore, played by foreign elements alloyed with iron, is either to hasten or delay the passage of iron, during cooling, to an allotropic state, and to render the change more or less incomplete in one sense or the other, according to whether the atomic volume of the added impurity is greater or less than that of iron. In other words, foreign elements of low atomic volume tend to make iron itself assume or retain the particular molecular form that possesses the lowest atomic volume, whilst elements with large atomic volume produce the inverse effect.

"It should be noted that carbon, whilst obeying the general law, possesses on its own account the property of undergoing, at a certain critical temperature, a change the nature of which is still disputable, although its existence is acknowledged. It is this property which gives carbon a place by itself in the metallurgy of iron."

M. Osmond has shown me the curves which represent the results of his experiments, and these will doubtless

¹ To the elements of column I. hydrogen may be added. As is well known, this element renders electro-deposited iron hard and brittle; perhaps it would be better to say with Graham *hydrogenium*, for hydrogen gas does not appear to have a marked influence on the critical temperature.

² Tungsten alone presents certain anomalies.

soon be published. Whatever may ultimately prove to be the true nature of the molecular change which accompanies the thermal treatment of iron and determines its mechanical properties, there is little doubt but that there is a close relation between the action of foreign elements and their atomic volume. Few metallurgical questions are of greater interest at the present time than those which relate to the molecular structure of metals, and the admirable work of M. Osmond has shown it to be very probable that the presence of a small quantity of a foreign metal may cause a mass of another metal to pass into an allotropic state. In relation to iron and steel the problems are of great industrial importance, and it is fortunate that we appear to be nearing the discovery of a law in accordance with which all metallic masses are influenced by "traces."

W. C. ROBERTS-AUSTEN.

SEDGWICK AND MURCHISON: CAMBRIAN AND SILURIAN.¹

ERRONEOUS impressions have long existed among American geologists with regard to the relations to one another, and to Cambrian and Silurian geology, of Sedgwick and Murchison. The Taconic controversy in this country served, most unreasonably, to intensify feelings respecting these British fellow-workers in geology, and draw out harsh judgments. Now that right views on the American question have been reached, it is desirable that the facts connected with the British question should be understood and justly appreciated.

Sedgwick and Murchison were literally fellow-workers in their earlier investigations. Prof. John Phillips, in a biographical sketch of Sedgwick (*NATURE*, vol. vii. p. 257), whose intimate friendship through fifty years "he had the happiness of enjoying," speaks thus, in 1873, of their joint work:—

"Communications on Arran and the north of Scotland, including Caithness (1828) and the Moray Firth; others on Gosau and the Eastern Alps (1829–31); and still later, in 1837, a great memoir on the Palæozoic strata of Devonshire and Cornwall, and another on the coeval rocks of Belgium and North Germany, show the labours of these intimate friends in the happiest way—the broad generalizations in which the Cambridge professor delighted, well supported by the indefatigable industry of his zealous companion."

Prof. Phillips then speaks of the Cambrian and Silurian labours "of two of the most truly attached and mutually helpful cultivators of geological science in England."

Of these Cambrian and Silurian labours it is my purpose to give here a brief history derived from the papers they published. They were begun in 1831, without concert—Sedgwick in Wales, Murchison along the Welsh and English borders.

In September of 1831, the summer's excursions ended, Murchison made his first report at the first meeting of the British Association. It was illustrated by a coloured geological map representing the distribution of the "Transition Rocks," the outlying Old Red Sandstone, and the Carboniferous limestone (Murchison, Report of the British Association, i. 91, 1831).

These "Transition Rocks" (of Werner's system), upturned semi-crystalline schists, slates, and other rocks, passing down into uncrystalline, and regarded as mostly non-fossiliferous, the "*agnotozoic*" of the first quarter of the century, were the subject of Sedgwick's and Murchison's investigations—the older of the series, as it turned out, being included in Sedgwick's part.² They were

early resolved into their constituent formations by Murchison, and later as completely by Sedgwick in his more difficult field.¹

Already in March and April of 1833, Murchison showed, by his communications to the Geological Society of London, that he had made great progress; for the report says:—"He 'separated into distinct formations, by the evidence of fossils and the order of superposition, the upper portion of those vast sedimentary accumulations which had hitherto been known only under the common terms of Transition Rocks and Grauwacke.' And these 'distinct formations' were: (1) the Upper Ludlow rocks; (2) the Wenlock limestone; (3) the Lower Ludlow rocks; (4) Shelley sandstones, 'which in Shropshire occupy separate ridges on the south-eastern flanks of the Wrekin and the Caer Caradoc'; (5) the Black Trilobite flagstone whose 'prevailing Trilobite is the large *Asaphus Buchii*, which with the associated species,' he observed, 'is never seen in any of the overlying groups'; and below these, (6) Red Conglomerate sandstone and slaty schist several thousand feet in thickness.

By the following January, 1834, Murchison was ready with a further report,³ in which he described the "four fossiliferous formations" in detail, and displayed, on a folded table arranged in columns, their stratigraphical order, thickness, subdivisions, localities, and "characteristic organic remains." The subdivisions of the rock-series in the memoir are as follows, commencing above: (I.) Ludlow rocks, 2000 feet; (II.) Wenlock and Dudley rocks, 1800 feet; (III.) Horderley and May Hill rocks (afterward named Caradoc), 2500 feet; (IV.) Builth and Llandeilo flags, characterized by *Asaphus Buchii*, 1200 feet; and, below these, (V.) the Longmynd and Gwastaden rocks, many thousand feet thick, set down as unfossiliferous.

Thus far had Murchison advanced in the development of the Silurian system by the end of his third year. Upper and Lower Silurian strata were comprised in it, but these subdivisions were not yet announced.

During the interval from 1831 to 1834, Sedgwick presented to the British Association in 1832 a verbal communication on the geology of Caernarvonshire, and another brief report of progress in 1833. A few lines for each are all that was published. The difficulties of the region were a reason for slow and cautious work.

In 1834, as first stated in the Journal of the Geological Society for the year 1852, the two geologists took an excursion together over their respective fields. Sedgwick says (Quarterly Journal of the Geological Society, viii. 152, 1852): "I then studied for the first time the Silurian types under the guidance of my fellow-labourer and friend; and I was so struck by the clearness of the natural sections and the perfection of his workmanship, that I received, I might say, with implicit faith everything which he then taught me." And further, "the whole 'Silurian system' was by its author placed *above* the great undulating slate-rocks of South Wales." The geologists next went together over Sedgwick's region, and

Werner, to our own, the belief was impressed on the minds of geologists that the great dislocations to which these ancient rocks had been subjected had entirely dissevered them from the fossiliferous strata with which we were acquainted."

The term "Transition" early appeared in American geological writings. Sixty to seventy-five years ago it was applied by Maclure, Dewey, and Eaton, to the rocks of the Taconic region and their continuation; for these were upturned, apparently unfossiliferous, semi-crystalline to uncrystalline, and extended eastward to a region of gneisses. The study of the rocks was commenced; but in 1842, before careful work for the resolution of them had been done—like that in which Murchison and Sedgwick were engaged—they were, unfortunately, put, as a whole, into a "Taconic system" of assumed pre-Potsdam age; at the same time "Transition" was shoved west of the Hudson, over rocks that were horizontal, and already resolved. Owing to this forestalling of investigation, and partly also to inherent difficulties, the right determination of the several formations comprised in this Taconic or "Transition" region was very long delayed.

² Murchison, Proceedings of the Geol. Soc. London, i. 470, 474, 1833; in a paper on the sedimentary deposits of Shropshire and Herefordshire.

³ Murchison, Proc. Geol. Soc., ii. 13, 1834. The subject was also before the British Association; Report for 1834, p. 652.

¹ Printed from advance sheets kindly supplied by Prof. Dana. The article appears in the current number of the *American Journal of Science*.

² Murchison says, in the introductory chapter of his "Silurian System," p. 4, "No one [in Great Britain, before his investigations began] was aware of the existence below the Old Red Sandstone of a regular series of deposits containing peculiar organic remains." "From the days of De Saussure and